NASA Aeronautics Safety Investment Strategy

Weather Investment Recommendations

SUMMARY

April 15, 1997

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1. Background

Weather is a factor in approximately 30% of aviation accidents. In addition, the majority of CFIT (Controlled Flight into Terrain) and "Loss of Control" accidents can be considered to be visibility-induced crew error, where better weather information or better pilot vision would have been a substantial mitigating factor. This report outlines the weather team's recommendations for a NASA investment strategy to reduce the number of future weather-related aviation accidents.

On February 12, 1997, President Clinton called for a five-fold reduction in the rate of fatal aviation accidents within a decade, and he announced that NASA will support this national safety goal by re-directing up to $500 million of research funding over five years. On February 18, 1997 NASA held the first in a series of four workshops to initiate Aeronautics Safety Investment Strategy Team (ASIST) activities. The team was chartered to propose a NASA investment strategy to support the national safety goal. The ASIST members were drawn from NASA, other government agencies (FAA, DoD, NWS), and industry. Five teams were formed to focus on specific areas of Human Error; Flight Critical Systems & Information Integrity; Weather; Aviation System-wide Monitoring, Simulation & Modeling; and Human Survivability. The teams were to deliver their proposals/plans at the final workshop to be convened on April 15-17, 1997.

The weather team had over thirty-five members who supported the team's discussions during teleconferences and workshop meetings. There was strong support from the meteorology community, with representatives from FAA, DoD, National Weather Service, Office of Federal Coordinator for Meteorology, National Center for Atmospheric Research, Aviation Research Inc., and MIT Lincoln Laboratory. Representatives from the Small Aircraft Manufacturers Association (SAMA) and the Air Transport Association (ATA) were active on the team. The team also had members from industry (Boeing, McDonnell Douglas, Sikorsky, GE Aircraft Engines, B.F. Goodrich, Cox and Co., and Continental Express) and universities (U of Illinois, Wichita State, and MIT). Unfortunately, many from industry were not able to actively participate in the team's discussions. As NASA moves on to more detailed program planning, a more active involvement from industry needs to be sought.

The goal of the weather element of ASIST is to reduce the fatal accident rates resulting from aviation weather phenomena by a factor of 5 over 10 years and by a factor of 10 over 20 years. This reduction is to be accomplished for commercial, general aviation *and rotorcraft sectors, given projected capacity increases and while either maintaining or improving efficiency.*

The team began by considering a broad, national investment strategy to meet President Clinton's safety goal. The team relied on a number of studies that have been recently completed on aviation weather and the accident statistics that were currently available. Although a reduction in fatal accident rate was the accepted program metric, the weather team also considered all NTSB's accident categories (Major, Serious, Injury, and Damage) and reportable incidents that are precursors to accidents. From this broad perspective, the team then defined those NASA-specific investments and research/development activities, recognizing that not all safety solutions required technology and research investments.

In identifying the recommended NASA investments, the team attempted to avoid duplication of efforts by other agencies or organizations. In fact, a strong cooperation and alliances between NASA, FAA, DoD, industry and academia are required for the nation to benefit from the investments recommended by the weather team. The proposed programs reflect those technology and research investments that were considered by the team to have the most significant impact on safety, i.e., increasing safety margins. Fundamentally, the weather team agreed that ALL specific activities toward this objective must be user-driven.

The weather team used the following process to develop this investment recommendation. The team considered a set of possible technology-driven solution paths toward eliminating all types of adverse weather as an aviation hazard. Solution approaches that the team adopted are collected into categories of Strategic Weather Information, Tactical Weather Information and Aircraft Systems, and Weather Operations. Strategic Weather Information technologies are critical for planning (either on the ground or in the air) a safe flight to avoid or minimize exposure to adverse weather. Updates of weather information from on-board sensors/systems and ground based weather systems, tailored toward the specific aircraft and flight path, can be used as Tactical Weather Information during flight. Aircraft Systems technologies that support avoidance strategies and/or safe operations through weather systems are a critical part of the weather solution path. Technologies in the Weather Operations portion of the team's solution path call for integrating strategic and tactical weather information, aircraft systems, and human factors.

The team then performed assessments of these critical technologies for specific weather factors grouped as Ceiling and Visibility, Convection and Winds, Icing, Turbulence, Wake Vortex, Volcanic Ash, and Runway Contamination. Potential project *areas were then defined with the team agreeing to levels of importance of these project areas. Investments in the potential project areas were then prioritized based on current accident data and projected future states.*

Definitions of accident rate, aviation weather and the critical technologies are given in Section 2. Team assessments of the critical technologies and potential project areas are given in Section 3. This report concludes with a description of weather-related investments recommended by the team in Section 4.

2. Definitions

A proposed definition for **accident rate** *is a combination of the projected future fatal accident rate (per million departures) for all aircraft operations in the United States (FAR Part 91 operation airplanes - General Aviation, Part 135 operation airplanes - Air Taxi and Commuters, and Part 121 operation airplanes - Large Transports), and the projected future international fatal accident rate (per million departures) for U.S. made commercial aircraft and U.S. airline operations. This definition specifies a projected future rate, the rate that would have occurred in the absence of this safety program (a potentially difficult value to establish). It specifies only fatal accidents, not all hull losses. It leaves out responsibility for foreign-made aircraft operated outside of the U.S., and business/general aviation aircraft of any manufacturer operated outside of the U.S., but it retains consideration of foreign made aircraft operating in the U.S., foreign airline operations in the U.S., and U.S. airline operations internationally with any manufacture of aircraft. Although the key metric for this program would be the fatal accident rate as defined above, research which leads to improved public perception of aviation safety or a substantial reduction in serious injuries and damage to aircraft will also be considered.*

Aviation weather *for this team is defined as any atmospheric condition that affects the operation and safety of an aircraft in flight or on the ground, including all forms of precipitation, low visibility (fog, haze, and night), icing, turbulence of all types (CAT, wake vortex, terrain induced, and convection), winds and wind shear, lightning, and volcanic ash. This definition is consistent with the definition adopted in the National Aviation Weather Strategic Plan but specifically includes wake vortex and night operations. Further definitions of the weather phenomena considered as causal factors in aviation accidents are given below.*

Ceiling & Visibility: all forms of precipitation, fog/haze, clouds, and light conditions.

Convection and Winds: strong winds and any predominately cloud system that has strong vertical motions in excess of 10 m/s.

Icing: accumulation of ice on aircraft surfaces, either from in-flight impact with super-cooled water droplets or from frost; precipitation of snow, drizzle or rain with subsequent freezing while engaged in ground operations.

Turbulence: all forms of atmospheric disturbance that cause aircraft of all sizes and categories to experience in-flight fluctuations in altitude, attitude, and airspeed.

Wake Vortex: atmospheric effects generated in the wake of a preceding aircraft in flight.

Volcanic Ash: projection of ash from eruptions of volcanoes high into the atmosphere, well into and frequently above jet flight altitudes.

Runway Contamination: accumulation of ice or compacted snow, loose snow or slush on runway surfaces; or patches of bare pavement (wet or dry) fully or partially covered with chemicals or sand.

Ceiling and Visibility *includes those weather and light factors that impact IMC vs. VFR flight, and the transitions between stages, from unlimited, marginal VFR, IFR, low IFR conditions (conditions reflecting below Category I, II, and III are important considerations).* **Convection and Winds** *refers to weather systems with strong vertical and surface motions and their impact on aircraft safe operations.* **Icing** *includes in-flight icing that may cause an increase in drag (potentially large and sudden) or loss of aircraft control resulting in roll and/or pitch anomaly, ice contamination during ground operation that can result in severe loss of lift or FOD (Foreign Object Damage) when ice is shed and ingested (especially by rear mounted engines), and carburetor icing.* **Turbulence** *causes aircraft to experience in-flight fluctuations in altitude and airspeed, resulting in discomfort at the low end of the spectrum, to injury and death of passengers and cabin crew, to in-flight structural damage and possible breakup in most extreme examples.* **Wake Vortex** *pertains to the potential low altitude aircraft upset caused by encountering the wake of a preceding aircraft.* **Volcanic Ash***, particularly common in the Pacific Ocean Ring of Fire region, can result in loss of all engine power and extensive damage to aircraft.* **Runway Contamination** *affects airplane* *performance by reducing takeoff acceleration through displacement drag (when the aircraft is forced to "plow" through contaminants) and through impingement drag (when contaminants are thrown into the air from "plowing action" and strike the airplane). Also, runway contaminants can seriously affect airplane braking action during landings. Overall, airplane performance penalties imposed by runway contaminants can quickly lead to serious aircraft accidents, if prudent operational practices are not strictly adhered to during these conditions.*

Technologies in the **Strategic Weather Information** *category seek to improve the quality, usefulness, and availability of aviation weather status and forecasts in order to better plan and conduct flights around/through weather systems. The team recognizes the importance of having ALL available and applicable atmospheric information accessible in suitable form and communicated to the pilot, Air Traffic Control (ATC), and airline dispatch operations. Technologies for sensing, collection, modeling and forecasting, weather product generation, and data dissemination are included in this category.*

Technologies in the **Tactical Weather Information and Aircraft Systems** *category address the safety issues associated with aircraft that needs to operate in marginal weather conditions or are inadvertently exposed to severe weather even with improved weather forecasting and data dissemination. Under these conditions, it is the on-board sensors/systems and weather tolerant design of the aircraft itself that ensure safe flight. Current on-board systems include ice protection systems (ice detectors and anti-/deicing systems), low-visibility precision guidance and displays, and weather/windshear radar. Some of these systems provide the flight crew with additional tactical information that can be used for re-routing decisions.*

The **Weather Operations** *category considers those technologies that better support operators, and includes simulation and hazard characterization; crew/dispatch/ATC hazard monitoring, display, and decision support; and crew/dispatch/ATC training elements. Simulation of effects of weather on aircraft systems and performance is required for hazard characterization that can be made aircraft-type specific. Research is needed that supports acceptable hazard characterization to define safe levels of weather conditions (e.g., for icing and turbulence). Crew/dispatch/ATC hazard monitoring, display, and decision support element requires information and human/machine interface technologies to integrate all available strategic and tactical weather information and aircraft state/performance/flight plan information to support safer operations. Crew/dispatch/ATC training element refers to transferring the knowledge from weather research to design better training material; targeting* *research programs to build databases, simulators, and visualization tools to use in training; and research into improving training methods.*

3. Assessment of Weather-related Technologies

To assess the investment needs for weather-related technology, the team created tables mapping accident causal factors and potential technology solutions. The team then considered the current states of the technologies that could be used to address the weather issues. The levels of current R&D funding efforts known to the team, regardless of the funding source, was also considered. From these assessments, the team considered potential project, or investment areas, that could be formed and discussed possible levels of importance of these project areas to GA and Transport community.

Team members worked hard to bring what was currently known by the membership into the discussions at the ASIST workshops and weather team teleconferences, but the team did not have the time to carry out in-depth analyses or research new information. The assessments relied primarily on judgment of those team members who were experts in various technology areas and on the experiences of those members who were technology end users. There was no attempt at quantitative scoring or discussions of criteria to be used for judgment. Still, the tables shown below indicate the consensus of the weather team.

Table 1 shows the weather team's assessment of the relative importance of the weather factors to General Aviation (G/A), Commuter, Transport, and Rotorcraft sectors. The tables show the weather factors causing aviation accidents along the rows. These factors are grouped as Ceiling and Visibility, Convection and Winds, Icing, Turbulence, Wake Vortex, Volcanic Ash, and Runway Contamination. Both fatal and non-fatal accidents were considered for the team's assessment. Accident data used for the assessment are included in the Background Information document.

Accident Rate Data (approx)								
G/A		Commuter		Transport		Rotorcraft		
Fatal	Non-Fatal	Fatal	Non-Fatal	Fatal	Non-Fatal	Fatal	Non-Fatal	Atmospheric/ Weather Hazard
1	1	1	1	1	2	1	1	**Ceiling & Visibility**
								Fog/Haze
								Precipitation
								Clouds
								Night Ops
3	2	2	2	2	3	2	2	**Convection and Winds**
								Thunderstorms
								Hail
								Heavy Rain
2	1	2	2				1	Winds
		2		2				Wind Shear
3	3	3	3	3	1	3	3	**Turbulence**
								Convection
								Terrain Induced
								Jet Stream
								Tropopause
								Gravity Waves
								Frontal
2	3	1	2	1	3	2	2	**Icing**
								In-Flight
								Ground
								Induction (Dew Point)
3	3	3	3	3	3	3	3	**Wake Vortex**
3	3	3	3	3	2*	3	3	**Volcanic Ash**
3	3	3	3	2	3	3	3	**Runway Contam.**

1	Significant Contributer to Accidents
2	Moderate Contributer to Accidents
3	Minimal Contributer to Accidents

Table 1 Accident Data Assessment

An assessments of relative maturity of technologies is shown below in Table 2, along with an assessment of current levels of R&D funding shown in Table 3. Possible technology solutions considered by the team are shown along the columns on the right hand side of the weather factors. The technology areas are grouped into areas of Strategic Weather Information, Tactical Weather Information and Aircraft Systems, and Weather Operations.

Table 2 shows the team's assessment of current technology/systems, with the red (number 1) blocks indicating minimal or no current capability, yellow (number 2) blocks indicating partially capable current technology/systems, and green (number 3) blocks indicating that current capabilities are reasonably adequate.

Current Technology/ Systems Assessment	Strategic Weather Information					Weather Information and Aircraft		Weather Operations		
	Sensing	Collection	Modeling and Forecasting	Product Generation	Data Dissemination	Sensors/ Systems	Weather Tolerant Aircraft Design	Simulation and Hazard Characterization	Crew/Dispatch /ATC Hazard Monitoring, Display, and Decision Support	Crew/Dispatch /ATC Training
Ceiling & Visibility										
Fog/Haze	2	2	1	2	1	2		3	1	2
Precipitation	3	2	1	2	1	3		3	1	2
Clouds	2	2	1	2	1	2		3	1	2
Night Ops	3	3	3	3	3	2		3	3	2
Convection and Winds										
Thunderstorms	2	2	2	2	1	3	2	3	1	2
Hail	2	3	1	1	1	2	2	3	1	2
Heavy Rain	3	2	2	2	1	2	2	3	1	2
Winds	2	2	2	2	1	1	2	3	1	2
Wind Shear	2	2	1	3	2	2	2	3	2	2
Turbulence										
Convection	1	1	1	2	1	1	2	1	1	2
Terrain Induced	1	1	1	1	1	1	2	1	1	2
Jet Stream	1	1	1	1	1	1	2	1	1	2
Tropopause	1	1	1	1	1	1	2	1	1	2
Gravity Waves	1	1	1	1	1	1	2	1	1	2
Frontal	2	2	2	2	1	1	2	1	1	2
Icing										
In-Flight	1	1	1	1	1	2	2	2	1	2
Ground	2	2	2	2	2	2	1	2	1	2
Carburetor	3	3	3	2	1	2	1	3	2	2
Wake Vortex	1	1	1	1	1	1	2	1	1	2
Volcanic Ash	2	2	2	3	1	1	1	1	1	2
Runway Contam.	2	3	1	2	1	2	1	1	1	2

1	Minimal or No Current Capability
2	Current Capability/Systems Partially Capable
3	Current Capability/Systems Reasonably Adequate

Table 2 Current Technology/Systems Assessment

Table 3 shows the team's assessment of current R&D funding levels, with the red (number 1) blocks indicating minimal or no R&D efforts underway or funded, yellow (number 2) blocks indicating moderate levels of R&D efforts underway or funded, and green (number 3) blocks indicating significant levels of funding. Areas of minimal or no current technology/system capabilities and areas of minimal and moderate levels of funding were then targeted for discussions of possible NASA investment areas.

Current R&D Assessment	Strategic Weather Information: Sensing	Strategic Weather Information: Collection	Strategic Weather Information: Modeling and Forecasting	Strategic Weather Information: Product Generation	Strategic Weather Information: Data Dissem-ination	Weather Information and Aircraft: Sensors Systems	Weather Information and Aircraft: Weather Tolerant Aircraft Design	Weather Operations: Simulation and Hazard Characte-ization	Weather Operations: Crew/Dispatch /ATC Hazard Monitoring, Display, and Decision Support	Weather Operations: Crew/Dispatch /ATC Training
Ceiling & Visibility										
Fog/Haze	2	1	1	2	2	2		1	1	1
Precipitation	3	2	1	2	2	2		1	1	1
Clouds	2	2	2	2	2	2		1	1	1
Night Ops						2				
Convection and Winds										
Thunderstorms	3	2	2	2	2	1	1	2	1	1
Hail	2	2	2	1	2	2	1	2	1	1
Heavy Rain	3	2	2	2	2	1	1	1	1	1
Winds	1	1	2	2	2	2	1	1	1	1
Wind Shear	3	2	1	1	2	2	1	1	1	1
Turbulence										
Convection	1	2	2	2	2	1	1	2	1	1
Terrain Induced	3	2	2	2	2	1	1	2	1	1
Jet Stream	1	2	2	2	2	1	1	2	1	1
Tropopause	1	2	2	2	2	1	1	2	1	1
Gravity Waves	1	2	1	1	2	1	1	2	1	1
Frontal	1	2	2	1	2	1	1	2	1	1
Icing										
In-Flight	2	2	2	2	1	2	2	2	1	1
Ground	2	2	2	2	1	2	1	2	1	1
Carburetor	1	2	2	1	1	1	1	1	1	1
Wake Vortex	2	1	2	2	2	1	1	1	2	1
Volcanic Ash	1	1	2	1	1	1	1	1	1	1
Runway Contam.	2	2	2	1	1	2	1	2	1	1

1	Minimal Or No R&D Efforts Underway or Funded
2	Moderate R&D Efforts Underway or Funded
3	Significant R&D Efforts Underway or Funded

Table 3 Current R&D Assessment

The proposed five-year investment areas within the weather element of ASIST are shown in Table 4. The ovals on the chart are a visual representation of these investment areas and also indicate the relationship between weather-related problems and technology-based solution elements. The proposed fifteen-year investment areas are shown in Table 5. From these tables, twelve distinct investment areas can be identified for funding during the next five years. These investment areas are Data Dissemination; Crew/Dispatch/ATC Hazard Monitoring, Display, and Decision Support; Icing; Crew/Dispatch/ATC Training; Weather Product Generation; Sensing, Collection, Modeling & Forecasting; Turbulence; Advanced Technology Vision and Tactical Sensors/Systems; Wake Vortex Strategic Weather Information Development; Sensors/Systems for Ceiling & Visibility and Convection & Winds; Simulation and Hazard Characterization; and Runway Contamination.

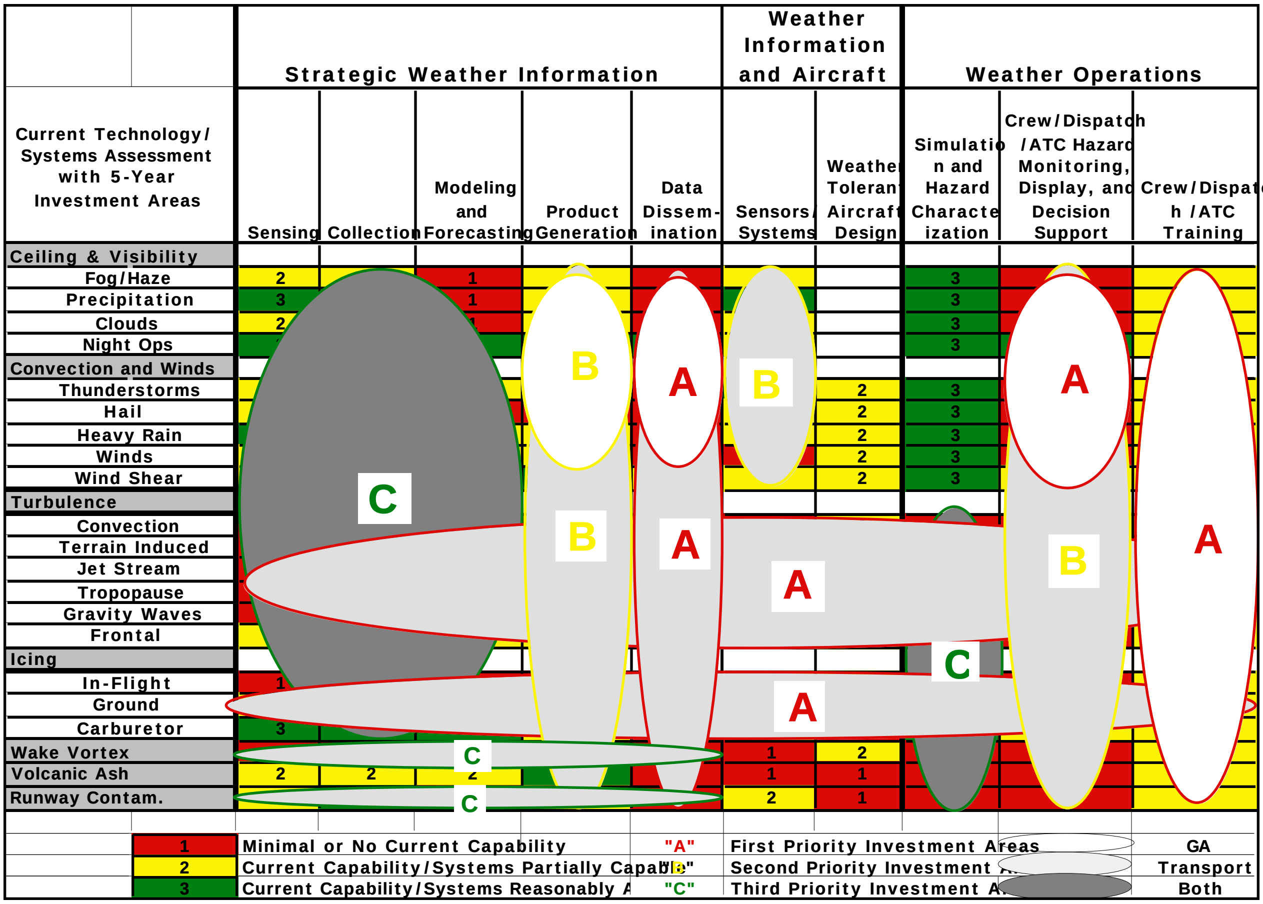

Table 4 Five-year Investment Areas

Proposed fifteen-year investment areas within the weather element of ASIST are shown in Table 5. Goals of some potential long-term projects are as follows;

- *Eliminate visibility-induced errors for* **all** *aircraft through the cost-effective use of synthetic/enhanced vision displays, worldwide terrain data bases, and GPS navigation*
- *Provide accurate, high resolution international nowcasts and forecasts, dissemination, display, and crew aids to allow safe and informed weather-related operational decisions*
- *Develop cost-effective integrated radar/lidar technology for tactical turbulence, windshear, icing, and wake vortex detection and warning*
- *Provide world-wide monitoring and immediate dissemination of volcanic ash hazards*

- *Provide common information/data parity/situational awareness for integrated aircraft/ATC/operations decisions*

	Strategic Weather Information					Weather Information and Aircraft		Weather Operations		
Current Technology/ Systems Assessment with 15 Year Investment Areas	Sensing	Collection	Modeling and Forecasting	Product Generation	Data Dissemination	Sensors/ Systems	Weather Tolerant Aircraft Design	Simulation and Hazard Characterization	Crew/Dispatch /ATC Hazard Monitoring, Display, and Decision Support	Crew/Dispatch /ATC Training
Ceiling & Visibility										
Fog/Haze	2			2	1			3		
Precipitation	3			2	1			3		
Clouds	2			2	1			3		
Night Ops	3				3			3		
Convection and Winds										
Thunderstorms					1	3	2	3		
Hail					1	2	2	3		
Heavy Rain					1	2	2	3		
Winds					1		2	3		
Wind Shear					2	2	2	3		
Turbulence										
Convection					1		2	1		
Terrain Induced					1			1		
Jet Stream					1			1		
Tropopause					1			1		
Gravity Waves					1			1		
Frontal					1			1		
Icing										
In-Flight	1			1	1			2		
Ground	2			2	2			2		
Carburetor	3	3		2	1	2	1	3		
Wake Vortex	1	1	1	1	1		2	1		
Volcanic Ash					1	1	1	1		
Runway Contam.	2	3	1	2	1	2	1	1		

1	Minimal or No Current Capability	"A"	First Priority Investment Areas
2	Current Capability/Systems Partially	"B"	Second Priority Investment Areas
3	Current Capability/Systems Reasonabl	"C"	Third Priority Investment Areas

Investment Area

Table 5 Fifteen-Year Investment Areas

4. Proposed 5 year Investment Plan

The identification of weather related factors that contribute to fatal accidents along with current technological capabilities and R&D efforts in weather hazard systems led to the creation of a proposed investment plan. This plan seeks to address those weather technology elements that, if successful, would have a significant impact on current fatal accident rates and on projected future fatal accident rates. In order to most effectively utilize the resources available, the plan is arranged into coherent investment areas that could independently affect the accident rate. That does not mean that each project can be or should be considered a purely Weather team investment. In fact, several of the potential projects will require close cooperation with other ASIST teams. In the end, it *is desired to create projects that will be multi-disciplinary in nature and that attempt to address the major problems associated with flight in adverse weather conditions.*

An initial estimate for the prioritization and funding of these investment areas is provided in Table 6. The priorities were based on the priorities shown in Table 4 and Table 5, an evaluation of the readiness and ability to impact accident rates in a timely manner, and a determination of the connectivity between the technology element and current NASA programs and expertise. Table 7 indicates the levels of funding from other ASIST elements to cover those solution that require technologies beyond weather team's consideration. The dollar numbers contained in these tables reflect the full cost of a particular program. As such, they include salaries of NASA personnel, overhead, facility costs, contracts, and grants.

3	Icing Hazard Solutions	3,000	6,000	10,000	9,000	7,000	35,000
4	Training	2,000	2,000	1,000	1,000	1,000	7,000
5	Weather Product Generation	2,000	6,000	5,000	4,000	3,000	20,000
6	Advanced Aviation Meteorology	4,000	4,000	4,000	4,000	4,000	20,000
7	Turbulence Hazard Solutions	3,000	3,000	2,000	3,000	4,000	15,000
8	Advanced Technology Vision and Tactical Sensors/System s	1,000	2,000	2,000	3,000	2,000	10,000
9	Near Term Tactical Sensors/System s	1,000	2,000	3,000	3,000	2,000	11,000
10	Strategic Wake Vortex Information	1,000	1,000	1,000	1,000	1,000	5,000
11	Hazard Characterization	1,000	2,000	2,000	0	0	5,000
12	Runway Contamination	1,000	1,000	1,000	1,000	1,000	5,000
		25,000	39,000	43,000	38,000	34,000	179,000

Table 6 Prioritization of investment areas and estimated funding profiles (in $1000)

Investment Areas	Additional Info Tech Funding	Additional Flight Critical Systems Funding	Additional Human Error Funding
Data dissemination	5	5	
Crew/Dispatch/ATC Hazard Monitoring, Detection, and Displa		5	10
Icing			
Training			20
Product Generation			
Meteorology			
Turbulence			
15 yr sensor/sys for C/V, Turb, Icing, W/V		10	
Vortex Shedding (TAP/AVOSS)			
Sensors/systems			
Hazard Characterization			
Runway Contamination			
Total	5	20	30

Table 7 Potential Funding from other ASIST elements

Brief descriptions of the investment areas recommended by the weather team are given in the sections below in the order of priority. Goals of the investment areas are given, followed by a listing of some potential project activities that could be undertaken to meet the goals. The lists of potential projects are not all inclusive, does it necessarily indicate endorsement by the weather team for any particular project, nor does indicate that they will necessarily be funded in the future. Since this is only a preliminary list, not a lot of details or background information are given. In some areas an augmentation in funding of currently funded NASA activities are indicated. Although not explicitly indicated with the project listing, a close cooperation between NASA and FAA are required in almost all project areas. In some of these areas there are already established cooperative programs between NASA and FAA that need to be continued or strengthened (e.g. the relationship between the NASA Lewis Icing program and the FAA Technical Center). In many program areas, close cooperation between NASA, FAA, and DoD is also required. Industry participation is also required.

4.1 Data Dissemination

The goals of this investment area are to develop, demonstrate, and implement a digital data link network capable of transmitting digital weather products. The target for general aviation or commercial users is to offer options at sufficiently low cost to encourage widespread use by December 1999 (U.S. coverage). By December 2001, the project will implement technology to transmit high bandwidth digital weather information to any suitably equipped aircraft worldwide. These projects will require strong partnerships with commercial suppliers.

Some possible project activities in this area are given below.

- *Develop a "research facility" for transmitting weather products to aircraft operating in all climatic regions, and collect pilot feedback on these products to evaluate weather products for their precision and accuracy, and for their efficacy as pilot decision tools. During the first year, conduct flight testing of current and developmental weather products.*
- *Validate a draft regulatory plan for in-flight weather products during the first year to issue appropriate certification and operational guidance necessary for widespread evaluations.*
- *Establish a secure ground communication network to both government and private weather dissemination sources to ensure parity of information between pilots, controllers, and dispatchers in the first year of this program. (Use existing NADIN II system).*
- *Augment existing data link systems by providing sufficient radio frequency spectrum for weather dissemination.*
- *Augment existing data dissemination project using the Flight Information Advisory Service Program at the FAA and the Aviation Weather Center.*

4.2 Crew/Dispatch/ATC Hazard Monitoring, Display, and Decision Support

An early focus of this investment area is to develop easy-to-use, effective cockpit displays and decision support tools to allow low-time general aviation pilots to readily avoid low ceiling and visibility and hazardous wind and convective weather conditions. On a broader level, the investment area seeks to develop advanced displays, automated monitoring, and decision aids for safe weather operations for flight crews, air traffic controllers, and airline dispatchers.

Some possible project activities in this area are given below.

- *Develop graphical presentation, customization, monitoring, and decision tool capabilities in the cockpit through widespread user evaluation in real operations.*
- *Explore augmenting the funding of FAA programs in this area (e.g. FAA AND-610 program) so that all segments of aviation operating in all climatic regions must be equipped with suitable displays to implement this program.*
- *Include controllers and dispatchers to be part of evaluations regarding how best to present both weather information and information on the products available to the pilot (e.g., flight plan weather data slant codes similar to currently used equipment codes).*
- *Support current NASA CWIN program.*

4.3 Icing

The goal of this investment area is to develop the capability to accurately forecast, detect, and/or alleviate icing as a hazard through integrating technology elements of Strategic Weather Information, Tactical Weather Information and Aircraft Systems, and Weather Operations.

Some possible project activities in Icing Weather Information, Icing Systems Technology, and Icing Operations are given below.

<u>Icing Weather Information</u> **-** *Improve the diagnosis and forecast (0-12 hr) of in-flight icing conditions (including expected type and meteorology-based icing intensities or categories) and to improve the state of knowledge for icing conditions currently outside the Appendix C certification envelop.*

- *Strategic Icing Weather Information Project - Produce accurate icing forecasts and develop products that will be useful for flight crews, ATC, and dispatch.*
- *Phase II Supercooled Large Droplet (SLD) Icing Project - A three-year flight program starting in FY 99 to augment the completion of the current NASA/FAA/NCAR cooperative effort to characterize SLD conditions initiated in FY 97.*

<u>Icing Systems Technology</u> **-** *Improve understanding of the relationships between aircraft design and inherent sensitivity to icing; improve and promote use of simulation tools to obtain more robust designs; and improve understanding of ice accretion and its effects on aircraft performance, stability, and control.*

- *Validation of Icing Simulations - Provide consistency between the various experimental facilities and computational methods with respect to representation of* *actual icing conditions, the resulting ice shapes, and effects on the behavior of model aircraft systems/subsystems.*

- *Phase II Tailplane Icing Project - Complete development of sub-scale test methodology and analytical tool verification for ice contaminated tailplane stall (ICTS) using sub-scale full aircraft tunnel tests, full-scale reflection plane tests, and flight tests to develop analytical tools for examining the potential for tailplane icing sensitivity and provide a robust screening mechanism to review existing designs.*
- *Smart Icing Systems Project* - *Develop the necessary technology for an aircraft to automatically operate and manage its ice protection system and modify its flight envelope to avoid maneuvers where flight could potentially be uncontrollable.*
- *Advanced Rotorcraft Ice Protection System Project - Develop an improved rotorcraft ice protection system that will meet the needs of rotorcraft operators in terms of reduced initial and operating cost, reduced maintenance and improved operational performance.*

Icing Operations **-** *Support the development of new methods of operating in response to known or unanticipated icing conditions.*

- *Phase I Remote Sensing Project - Implement the development plan to assess the use of onboard remote sensing to characterize the local icing conditions around the aircraft and provide information needed for avoidance capability.*
- *Icing Operations Educational Project - Develop an educational program that includes a visual story of what types of ice exist and their potential impact on the aircraft, and typical strategies that can be used as decision aids during an icing encounter.*
- *Icing Flight Simulator Development Project - Develop a simulation of flight in icing that includes stall behavior, changes to stability & control characteristics, and visual cues to the presence of ice for effective pilot training.*

4.4 Crew/Dispatch/ATC Training Project

The goal of this investment area is to develop new technologies and methods for operationally oriented weather safety training. Initial effort seeks to effectively disseminate state-of-the-art information on aviation weather and its effects on aircraft performance.

Project activities in this area are intended to supports all weather issues and require close coordination with and support from the ASIST Human Error team. One option for implementation of some of the project elements would be to use Cooperative

Operational Meteorology Education and Training program (COMET) from the University Corporation for Atmospheric Research (UCAR) as a training focal point to explore, analyze, test, and help build suitable aviation weather training environments for forecasters, dispatchers, and flight crew.

4.5 Weather Product Generation

The goal of this investment area is to develop/improve the products available for interpreting weather information for both GA and commercial transport use.

Some possible project activities in this area are given below.

- *Support the funding of the FAA's Aviation Weather Research Program (AUA-460) on Weather & Atmospheric Hazard Avoidance*
- *Evaluate current FAA/NCAR/NOAA/private sector graphical weather products for use by pilots, controllers, and dispatchers.*
- *Develop and evaluate additional pilot decision tools using NEXRAD and Aviation Impact Variables.*
- *Develop and validate minimum color/texture and product descriptor standards for graphical weather products usable for in-flight decision making to provide spatial and temporal specificity for all users as well as uniform interpretation standards.*
- *Provide additional support for Aviation Impact Variables, the Alaska Aviation Weather Unit, and the Aviation Weather Center product development efforts.*

4.6 Sensing, Collection, Modeling & Forecasting

The goal of this investment area is to improve safety by identifying hazardous weather conditions and applying the science and technology of meteorology to assist in reaching this goal. Investments in the first 5 years of the ASIST program ensures a strong start toward meeting the 15 year strategy shown in Table 5.

Some possible project activities in this area that specifically support Ceiling and Visibility, and Convection are given below.

<u>Ceiling and Visibility</u> - Improve ability to predict ceiling and visibility changes for both en route and terminal area needs.

- *Improve ability to observe and forecast very high spatial resolution variability of C/V within 100 km of major air terminals*

- *Aim for forecast 6 hr duration*
- *Embed very high resolution models of terminal area weather within existing NCEP operational models*
- *Uses "Intelligent Weather System" IWS techniques*
- *Improvements to operational general-purpose NWS/NCEP models which are necessary to provide more accurate predictions of hydrologic variables such as cloud water, humidity, and precipitation rate and type*

<u>Convection</u> - *Improve warning and forecasts of all aviation-critical convection phenomena (including nowcasting of thunderstorms, hail, heavy rain, lightning, low-altitude wind shear, microbursts, and strong gusty winds at airports), establishing a connection between convection research and the turbulence impact of flight near convective storms.*

- *Improve detection and nowcasting of hail and heavy rain*
- *Develop ground simulation capabilities for heavy rain to study its effects on aircraft/engine performance*
- *Analysis of existing polarimetric data*
- *Conduct additional field programs in diverse regions to test and refine algorithms*
- *Improve tornado mesocyclone detection and nowcasting*
- *Continue analysis of existing NEXRAD and VORTEX data*
- *Develop refined algorithms that handle tornado mesocyclones*
- *Improve microburst nowcasting algorithms by determining if precipitation phase information from polarimetric data can improve warnings*
- *Develop and improve techniques for detecting and nowcasting of strong low-level winds, wind shifts, and wind shear by detection and extrapolation techniques to be enhanced by winds from adjoint models (radar and mesonet data)*
- *Improve nowcasting of thunderstorm initiation, dissipation, and intensity*
- *Use adjoint models to retrieve high resolution low-level fields of winds and temperature*
- *Combine radar and satellite data to locate convergence lines and monitor cumulus cloud evolution*
- *Refine rule-based systems*
- *Field test at operational locations and refine user products*

4.7 Turbulence

The goal of this investment area is to develop the capability to accurately forecast, detect, and/or alleviate turbulence as a hazard through the most capable and cost-

effective means possible. The work encompasses turbulence affecting all sizes and categories of aircraft and all generating phenomena.

Potential project activities given below includes consideration for convective storms, terrain-induced, jet stream, tropopause, gravity waves, and frontal systems. Project activities that focus on specific causes of turbulence could also be conducted, e.g., an effort to improve safety of flight in approach and landing by providing strategic weather information for hazardous gravity waves/buoyancy oscillations at low altitudes.

Sensing - Improve currently utilized approach to sensing of turbulence (algorithms that incorporate flight and pilot parameters to extract atmospheric signals of turbulence from aircraft motion) and potential future options (forward-look remote sensing using lidar systems to see velocity changes or IR systems to see temperature changes).

- *Improve turbulence reporting by sensing and reporting turbulence from at least 50% of the general aviation and commercial fleet.*
- *Develop and validate robust forward-look technology using lidar and/or IR.*
- *Develop algorithms for remote sensing of turbulence using radars, wind profilers, lidars, satellites, and surface wind networks.*

Collection - Seek significant improvement in this area, since the collection of turbulence data is the poorest example currently in the domain of hazardous weather (PIREPS currently provide the only useful sensed information, and 90% of the turbulence PIREPS are never encoded and made available).

- *Develop a turbulence data collection system capable of cataloging high-resolution automated PIREPS at the volume anticipated from the in-situ turbulence system.*

Modeling and Forecasting - Improve forecasts by increasing spatial and temporal resolution and intelligent use of sensed data from aircraft and remote sensors.

- *Integrate data sensed from aircraft and with remote sensors into higher space/time resolution models using 4D variational data assimilation.*
- *For short term nowcasting of turbulence, integrate aircraft-sensed data, remote-sensed data, and model information in an intelligent algorithm to produce highly accurate data sets.*

Product Generation - Develop, operationally demonstrate, and evaluate a turbulence product that can be used by a pilot, in flight, as an effective decision tool. Make a *similar product available to controllers for tactical use. Today's NWS turbulence products are not particularly useful to pilots, controllers, or dispatchers, except as a "heads up" message, since they cover large areas where the actual turbulence over the specific route of flight is not known.*

4.8 Advanced Technology Vision and Tactical Sensors/Systems

Investments in this area are needed during the first 5 years of the ASIST program to lay the ground work for meeting these high priority goals over the 15 year horizon (see Table 5). This would focus on in-situ and forward-looking aircraft sensing, and systems development that would include integration of sensing and forecasting capabilities throughout the system to provide advance capability. Advancements in weather tolerant aircraft design would also be sought.

4.9 Wake Vortex

The goal of this project is to develop a system to ensure safe vortex separations during terminal area operations. Currently funded TAP/AVOSS wake vortex program could be augmented.

4.10 Sensors/Systems for Ceiling & Visibility and Convection & Winds

The goal of this investment areas is to develop on-board aircraft system capabilities to recover from aircraft upset. Continued development of Global Positioning Systems (GPS) hardware, the infrastructure to enable the use these sensors, and research for the necessary regulatory changes to fully capture the benefits of GPS should also received continued emphasis.

4.11 Simulation and Hazard Characterization

The goal of this investment area is to quantify the relationship between the physical phenomenon of aviation meteorology and the level of aircraft operational hazard for turbulence, icing, wake vortex, and volcanic ash.

4.12 Runway Contamination Strategic Weather Information Development

The goal of this investment area is to improve the sensing, collection, and reporting of runway conditions/breaking action in operational use. Current programs in this area should be augmented.